How to Build up Furnace Efficiency

—BY—

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"Combustion and Smokeless Furnaces"
"Flue Gas Analysis"
"A Manual of Gas Analysis"
, Etc.

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Preface To The Third Edition.

The reception accorded this little work has been a source of great gratification to the author. The surprise has been as great as the gratification. The booklet has reached its third edition in seven months from the initial publication. The subject treated is apparently one of the most lively interest to the engineering fraternity, and letters have been received from leading engineers in all parts of the English-speaking world endorsing the views and contentions of the writer.

The booklet was originally offered in the belief that nothing existed in engineering literature properly bearing upon the practical application of gas analysis to the problems of every-day boiler-furnace practice. The author has endeavored to avoid a theoretical treatment of the subject as far as possible, and to deal with the problems that are, or should be, recognized by every operating engineer.

An impression has been current among steam engineers that gas analysis belonged entirely to the domain of the chemist, that

its application to steam engineering was more far-fetched than practical, and that technical training was necessary to the use of the gas analysis instrument. No view of this matter could be more erroneous, and one purpose of the booklet is to correct these existing impressions. An effort has been made to strip the subject of some of the false mystery surrounding it.

The subject matter of the booklet has been slightly revised for this edition, and the author hopes that such revision has been in the way of improvement.

Jos. W. Hays.

Chicago, March 1, 1909.

How To Build Up Furnace Efficiency.
Don't Try To Go Up From The Top Down.

How shall we proceed to build up the efficiency of our boiler furnaces? In other words, how shall we move toward the end of cutting down our coal bills?

Most operating engineers will return very indefinite answers to the above queries, and no more important questions were ever propounded in a steam power plant. The greatest wastes that take place in the establishment are the inexcusable losses that occur at the source of energy, the boiler furnace.

How large are the unnecessary losses, referable to the furnace? I would estimate them in the average plant at ten per cent. of the fuel consumption. This may seem like over-enthusiasm on the subject; but the estimate is, if anything, on the safe side of the premises. Horrible examples running as high as forty per cent. have come under my personal observation.

You can burn a lot of coal and make a little steam, or you can burn a little coal and make a lot of it. It all depends upon how the furnaces are managed.

Is one-tenth of your coal pile worth saving? It is a waste of good paper to print such a question.

"The Economical Combustion of Fuel" is the most important and engrossing subject this moment in the whole purview of steam engineering. The wastes due to unscientific furnace operation, without doubt, exceed the sum of all other wastes taking place in the power department. Why have we permitted these losses to run their course unheeded? It is the most unexplainable thing in the history of power production.

There are dollars to be had at the furnace and nothing but dimes at the engine. The men who pay the coal bills are slow to make this discovery; but they are waking up, and the alarm clock may go off at any moment in your institution. I quote the exact language of a Chicago engineer, "The time has come when the engineer must interest himself in the subject of combustion, otherwise engineering will not interest itself in him." The steam engineer will do well to take account of the way events are drifting.

How then shall we proceed to build up furnace efficiency—how can we go about it to get the same steam with a less consumption of fuel?

I use the expression "build up," because a constructive matter is contemplated. It is a case of "one brick upon another"—all of the processes necessary to increase furnace efficiency being step by step operations. There is a place to start, a plan to be followed and a result to be attained. It is in every sense a progressive or building-up operation. This being true, it be-

comes important to start right, to begin at the beginning and build with intelligence, otherwise the structure we erect will be a curious and lop-sided piece of architecture.

A ready method of testing the furnace must be adopted before we begin our building-up operations. We cannot build without a plumb, square and level. Suppose, for example, we reduce the draft a little or do any one of a dozen other things in connection with furnace management. Have we moved in the wrong or the right direction? Are we house wreckers or building contractors? The effect of each step as it is taken must be determined before we proceed to the next one, and but one step must be taken at a time; for if two things are done at once we have no means of knowing to which we must attribute the effect noted. The tests that we employ must yield us immediate as well as positive information. There is no sense in waiting a week for an answer that may be obtained in a minute.

What manner of test should be applied to the boiler furnace? Nine out of ten engineers will tell us, "The evaporation test." It is an incorrect answer; but it comes with uniformity, for it is the only test with which the average engineer is acquainted.

Such manner of furnace test is a tail-foremost operation—an attempt to build up from the top down, to put on the finals before laying the footings. When we are testing a furnace we are inter-

ested exclusively in furnace matters, and the evaporation test yields only the most general answer to any strictly furnace question. It is the final test to apply in determining the efficiency of the boiler room—the combined efficiency of the boiler, the furnace, the coal and the fireman. Such composite efficiency it correctly expresses, but it does not differentiate between the faults that belong to the boiler and the other faults that are chargeable to the furnace, the fireman and the coal.

Furnaces and stokers are often sold with certain guarantees as to evaporation. No more unfair or unscientific thing could be written into the specifications.

Ten men are engaged upon a common job—unloading a barge of coal, for example. Some are workers and others are "soldiers." Can you pick out the loafers by taking stock of the coal unloaded at the end of the day? Of course not. The work of each individual in the gang must be under direct observation.

If we are to test the furnace with any hope of arriving at positive knowledge of its efficiency, we must eliminate from the equation every factor except the furnace. No question as to boiler efficiency must enter into the problem and add its complications. There are boilers and boilers; tea kettles and modern steam generators; boilers that have been physicked with compounds and never introduced to a tube cleaner. When it comes to evaporation it makes a lot of difference what kind of a

boiler is hitched up to your furnace, and it makes, if anything, still more difference the condition that boiler is in.

It is true that all of the factors in a power plant from bunkers to bus-bars are interrelated, very closely, the one to the other, and that a line upon any one of them furnishes some information as to all of the others. There is a close connection between coal and kilowatts and an intimate relation between the furnace and evaporation. This involved relationship is one of the things that disqualify the evaporation test as a measure of furnace efficiency. You find the evaporation is low. Why is it low? What can you do to improve it? These are pertinent questions, and, unless you can answer them, there is little "rhyme" and less reason in conducting a test to determine the evaporation. I shall continue to quarrel with the evaporation test until a separate and searching test is at the same time applied to the boiler furnace.

What is the true function of the boiler furnace? To transform the heat energy contained in the coal—to change this energy from the potential to the available condition and deliver it in such condition, undiluted and unmodified, to the boiler. What is the function of the boiler? To evaporate water, to take the heat energy delivered by the furnace and use it in the manufacture of steam. The boiler has no business with combustion, and the furnace is only indirectly concerned with evaporation.

The proper form of test enables us to set the furnace up as a separate individual entity and examine it as such without reference to anything else under the firmament. We must make a searching examination, count the pulse, and listen to the heart beats, as it were. Are the disorders of the furnace functional or organic? There can be no prescription without a diagnosis and no diagnosis without an examination. We must have a form of test that goes straight to the root of the matter and that will enable us to correctly diagnose and intelligently prescribe.

What is the true criterion of furnace efficiency? Unless we know an efficient furnace when we see one, there is little use in proceeding with any testing operations.

THAT FURNACE IS THE MOST EFFICIENT WHICH COMPLETELY CONSUMES THE COMBUSTIBLE WITH THE LEAST SURPLUS OF AIR.

The above definition entirely circumscribes all questions bearing upon furnace efficiency. No matter where we start or in which direction we proceed, whether we are considering the subject of drafts, of fuels, of methods of firing, or what not, we are brought, in the end, inevitably back to this proposition. In the last analysis it includes the answer to every problem relating to the economical consumption of fuel. Fix it in your mind, and much of the mystery will fall away from your combustion problems.

ARE WE BURNING ALL OF THE COMBUSTIBLE WITH THE LEAST SURPLUS OF AIR? Flue gas analysis answers this question and all others correlated or collateral to it. No other form of test ever has been or ever will be devised to supersede it. The furnace exists solely for the gases that are delivered from it, as it is from these heat-laden gases, and from them only, that the boiler derives the heat energy necessary to its functions. It follows, therefore, as a matter of logic, that every judgment upon the furnace must be based upon an inquiry into its gases. These gases are the fruits of the furnace. "By their fruits ye shall know them."

I have recently been informed by three of the leading furnace and stoker manufacturers that all of their proposals, guarantees and contracts will in future be based entirely upon furnace performance and without any reference to the boiler—whether it evaporates much or little. This I regard as the beginning of a universal movement in the right direction. It is recognition of the fact that the furnace is one thing and the boiler another. Must one try on his overcoat to tell if his pants fit?

It is my present purpose to show how gas analysis may be applied in finding the answer to every possible question bearing upon furnace efficiency. I shall not dwell at any length upon the theory and chemistry of the matter, as I have treated of these elsewhere.* A knowledge of the

* See "Combustion and Smokeless Furnaces."
"A Manual of Gas Analysis."
"Flue Gas Analysis."

chemistry of combustion is highly desirable, but it is not necessary to fit any one for the work of gas analysis or the intelligent manipulation of a furnace. The sharpshooter does not need to know the chemical constitution of the powder in the cartridge in order to make a bull's-eye. The practical uses of gas analysis are of the utmost concern to the engineer, while the theory of the matter has only academic value.

The product of the complete combustion of Carbon is CO_2, or Carbon Dioxid, and everybody knows that the principal constituent of coal is Carbon. A given weight of coal (Carbon) will accordingly produce a given weight of Carbon Dioxid. Assuming the fuel to be straight Carbon and that complete combustion is taking place with the theoretical quantity of air (an altogether impossible state of affairs in furnace practice), we should have 20.7 per cent. by volume of CO_2 in the furnace gases. The air contains this percentage of free Oxygen, and when Oxygen combines with Carbon to form CO_2, the volume of the gas produced exactly equals the volume of the Oxygen consumed.

Now if we employ about 40 per cent. excess air—the condition of reasonably good practice—the chimney gases will be diluted by the excess and the volume of CO_2 will be a smaller percentage of the total volume of the escaping gases. This 40 per cent. excess air absorbs heat energy and carries it up the chimney. The heat so absorbed is an utter loss, and, together

with the loss due to the Nitrogen of the theoretical air supply, represents about 11½ per cent. of the fuel. Analysis of the gases under such conditions will show about 14¾ per cent. CO_2. If we increase the air supply to 100 per cent. excess, the percentage of CO_2 will be 10.35 and the loss in fuel around 18 per cent. Every time the air supply is doubled the percentage of CO_2 is halved.

Suppose we have a quart of milk that is 20.7 per cent. cream. We add a quart of water and our two-quart mixture is now 10.35 per cent. cream. If we add two more quarts of water, giving us four quarts in all, the mixture will be 5.17 per cent. cream. Doubling the air supply works the same mathematics on CO_2 that doubling the water added works on cream. If this illustration is not comprehended by engineers, it will be understood by milk dealers.

It should now be understood why the lower we go in the scale of CO_2 the greater will be the waste that the loss of each succeeding per cent. of the gas represents. For example, if we drop from 16 per cent. CO_2 to 10 per cent., the loss due to this drop of 6 per cent. is 4 per cent. in fuel, while the loss due to dropping from 10 per cent. to 4 per cent. CO_2 is 18 per cent. in fuel. Furnace conditions grow worse in a geometrical ratio of progression as we descend in the scale of CO_2 percentages. I offer the figures here given by way of explanation of this fact.

It must be remembered that all such

figures as the above are based upon an assumed set of conditions. The fuel is assumed to be straight Carbon, which is never the case, and the stack temperature is assumed to be 500 deg., which may or may not be the case. The higher the stack temperature the hotter we are heating the excess air, and the hotter we make it the more fuel we are wasting for the purpose.

No engineer can compute his gains and losses from any such table of figures. The only value in such mathematics lies in the fact that it expresses in a general sort of way what is occurring. Keep a daily record of your CO_2 averages and figure your gains and losses from the coal bills at the end of the month, taking full account, of course, of the duty performed and other matters too superfluous to suggest to the engineer.

The bulk of the losses due to faulty furnace operation are chargeable to excess air. Don't flatter yourself because your stack is clear that you are operating your furnace economically. You may be passing a thousand per cent. excess atmosphere through your furnace and across the heating surfaces of your boiler. Instead of a power plant, you may be running a hot air factory.

"I would rather see 50 per cent. combustible in the ash than bare spots at the rear of the grates." The above statement was recently made to me by a prominent manufacturer of boilers and stokers. You can run coke into the ash pit with some

chain grate stokers and save money. Combustible in the chimney gases is an evidence of wasted energy; but if we are looking for sick furnaces, we must visit the clear stacks as well as the smoking chimneys. Coke and anthracite, or a coked fire of bituminous coal, are not productive of smoke, and yet we all know that the stack gases may be full of combustible from such fuels.

Low CO_2 may be accounted for upon one of two theories:

1st. The presence of excess air in a redundant quantity.

2nd. Incomplete combustion and the presence of CO or other combustible gases.

Both of the above conditions may obtain simultaneously. We may also find CO in the presence of a high percentage of CO_2. For example:

We may be passing a vast quantity of excess air through the furnace while at the same time some of the conditions necessary to combustion may be lacking. There may be incomplete mixture of the air with the gases, the temperature in the combustion area may be too low for ignition, or the flame may be chilled upon the cold heating surfaces of the boiler before the act of combustion is completed. This would mean a case of the worst possible furnace conditions in combination.

We may, again, have good furnace conditions with 12 to 14 per cent. CO_2. If we still further reduce the air supply we may get as high as 14 to 16 per cent. CO_2 and find that we are also getting CO, the

reduction of the supply of excess air putting up the percentage of CO_2 at first faster than the formation of CO reduces it. If we continue cutting down the air supply, the volume of CO will exceed the increment of CO_2, and the analysis will show a rapidly falling percentage of Carbon Dioxid.

The territory between no smoke—no combustible in the gases—and highest efficiency is fixed by very narrow boundaries. Let us draw a horizontal line and consider it as lying in the plane of highest furnace efficiency—complete combustion with the minimum supply of excess air. Above this line is the territory of unnecessary excess air, and below it the territory of air deficiency. The higher we go above this line the nearer we are approaching "hot air factory" conditions. The further we go below it the nearer we come to the gas producer and the conditions of destructive distillation. If we remain in the neighborhood of the line, fluctuating furnace conditions will place us first upon one side and then upon the other of it. There will be periods of no smoke, succeeded by periods of slight smokiness. Such conditions at the stack usually point to economical furnace operation. If there is no smoke at all, we have no means of knowing from mere stack observation to what extent the furnace may be indulging in excess air.

Whatever the cause, the percentage of CO_2 in the stack gases may be accepted as a closely approximate measure of fur-

nace efficiency. Much depends upon the conditions under which the gas sample analyzed is taken, particular reference being had to the locality from which the sample is drawn. It is necessary for the engineer to employ his reasoning faculties in order to determine the true economic meaning of any analysis. I will endeavor to make these matters clear as I proceed.

Having settled upon flue gas analysis as the form of test to be employed, it is next necessary for the engineer to supply himself with the proper analyzing apparatus. There is occasion here for some discernment, as he must select an apparatus adapted for building-up operations. A multitude of combustion questions are to be asked and answered. He must analyze, dissect and pick to pieces the entire furnace situation. I am assuming that the engineer is already provided with a proper draft-gage. A thermometer for taking stack temperatures will be useful, if not absolutely necessary, while the draft-gage is indispensable. A simple form of draft-gage may be had for about $3.00, which may be made to answer, or the engineer may manufacture a fairly good one by heating and bending a piece of glass tubing.

A really good gage of sufficient accuracy for taking the draft at the furnace will cost about $10.00. It should be remembered that the draft at the furnace is the draft that does the business, and that a difference of a twentieth of an inch in the pressure at this locality may

mean a very marked difference in coal consumption.

Before considering the various types of gas analysis apparatus from which the engineer must make his selection, it will help us to an understanding of the situation if we first inquire what the real offices of the gas analysis instrument are when it is employed in the furnace room.

Flue gas analysis serves two purposes to the engineer, as follows:

First, and most important: It points out the errors of furnace management—locates the wastes of energy, assigns the causes and suggests the remedies. It assists in "building up" furnace efficiency.

Second: It serves as a check upon the furnace and the fireman, and assists in maintaining efficiency after the "building-up" operation has been completed.

It is evident that efficiency cannot be MAINTAINED until it has been first ATTAINED. The first and more important job is to capture the animal; the second job is to safely corral it.

If a high state of efficiency was the rule among boiler furnaces instead of the exception, then these two offices that I have mentioned might be reversed in the order of their importance. There is always room for improvement in the boiler room. No furnace can be operated under ideal conditions, for reasons that are known to every operating engineer. The load fluctuates, the draft varies, and the moods of the coal dealer are subject to changes. It is a case of eternal vigilance in the fur-

nace room and "building day by day," as the hymn that the engineers sing at camp-meeting has it. Show me a state of furnace conditions beyond criticism and I will show you an engineer that is "ripe for glory."

The best the engineer can do is to do the best he can do, and it is a foolish man who will not try at all because he knows an ideal state of conditions is unattainable.

The practical gas analysis apparatus for boiler furnace work must fill both offices that I have mentioned. It must locate the troubles of the furnace and point out the remedies. It must assist in "building up furnace efficiency," and it must report the first disposition upon the part of the furnace or the fireman to destroy the structure after the building is completed. These two offices must be distinctly kept in mind when the gas analysis apparatus is selected. Can you "build up" with the instrument the salesman is trying to sell you? Will it keep a daily watch upon your furnace and your fireman? If "Yes" to both questions, then it is the apparatus you are after. The question of cost is a minor consideration, for the apparatus will pay for itself many times over, no matter what the cost of it.

The practical apparatus for boiler furnace work must, incidentally, meet these additional specifications:

1st. It must yield a ready and positive answer to every furnace question that may be propounded to it. To this end it must

be portable, or ready for business on a moment's notice at any point in the furnace room. It must give the percentages of Oxygen and CO, as well as CO_2, as a knowledge of these percentages is, under some circumstances, of considerable importance.

2nd. It must be simple in form, easily operated, and not likely to get out of order. If an expert is required to understand and run it, then it is not a practical apparatus for every-day boiler-room work.

There are three forms of gas analysis instruments on the market for use in furnace work.

1st. The simple hand-manipulated instrument, giving Oxygen and CO, as well as CO_2. It is an inexpensive apparatus, and if used in connection with a gas-sampling vessel, will answer every practical demand that the engineer may make upon it. The average record for the day is secured from the sample in the sample-receiving vessel.

2nd. The automatic CO_2 Indicator. This instrument automatically analyzes at recurrent short intervals, and indicates the percentage of CO_2 on each analysis.

The indicating gage of this instrument, which is in some respects similar to the familiar draft gage, may be placed upon the boiler front, while the instrument itself may be situated in a more secure position. The fireman accordingly has an expression of his efficiency as an operative constantly before him, and may guide his manipulations of the furnace according to its indications.

One objection to the Indicator lies in the fact that it makes no record of the daily averages. The fireman may record memoranda of the readings at frequent intervals, and the daily average may in this way be arrived at by computation. The objection to this is that most firemen cannot be trusted to watch a clock and gage for this purpose. With all due respect to the fraternity, I must also urge that temptation would exist to write down false records of efficiency when no one was present to dispute the accuracy of the gage readings.

Beef and bone can heave coal, but it takes brains to make a good furnace operative. False ideas of economy have led us to establish a scale of wages for the fireman that cannot look good to the man with brains enough to grasp and solve furnace-room problems. We occasionally find extra intelligence at the shovel, but this is the exception to the rule that proves the predominance of mere muscle. Even in some of our larger plants employing mechanical stokers, we find the most ordinary men in charge of the furnaces—a combination that always results in the most haphazard and wasteful methods of furnace management. Some few of the larger establishments have tried the experiment of employing a "superintendent of the furnace room," whose business it is to see that the furnaces are properly managed. Such a man, if he understands his business, will earn his salary many times over.

Can your firemen be trusted to diagnose

furnace conditions and select the right remedies, in the light of what the CO_2 indicator tells them? Would it not be better to diagnose the case yourself and lay down a set of rules for the management of your furnaces, relying upon the analysis of the average samples of gas trapped by the sample-receiving vessels to tell you whether these rules have been observed or otherwise? Suppose, for example, you have learned by experiment that a certain combination of conditions as to draft, etc., etc., will carry your load and give the highest obtainable efficiency consistent with your circumstances, showing an average of, we will say, 12 per cent. CO_2 in the flue gases, you then lay down your rules of furnace management to the fireman. You find at the end of the day he is making an average of 8 to 10 per cent. Carbon Dioxid instead of the 12 per cent. that you have proved to be practicable. It is up to the fireman to explain in what particular he has failed to carry out your instructions.

The CO_2 Indicator is not at all adapted to the building-up operations we are about to consider, and, if employed, it must be reinforced by the use of the hand instrument referred to. The hand instrument must be reinforced in turn by the automatic sampling vessel, as it is necessary to obtain the correct average of the CO_2 and sometimes that of the O and CO for the day's run. It is such averages that express the efficiency of the furnace.

The hand apparatus and sampling ves-

sel can get along without the Indicator, but the Indicator cannot travel very far without the other instruments.

An ideal outfit for the large power establishment would be an automatic gas sampling vessel and automatic CO_2 Indicator for each boiler furnace, and at least one hand analysis instrument for the plant. The Sampling Vessel enables us to get the daily averages, the Indicator expresses the conditions obtaining from moment to moment, and the hand analysis instrument meets the situation in the checking-up process incident to the work of building up efficiency.

3rd. The automatic CO_2 Recorder. I must comment at some length upon this rather marvelous instrument, for I cannot afford to be misunderstood, and the interests of engineering demand that the truth be told about the apparatus—its advantages and limitations. I call it a marvelous instrument, for it is in reality an automatic chemist, and possessed of an intelligence that is sometimes lacking among the humans in the laboratory.

Just the same, a machine may be ever so marvelous in its make-up and in its operations, and still not fall within the category of strictly practical apparatus for the purpose aimed at. It may be ever so practical and still not be justified in making claim to the marvelous. The engineer is interested only in practical apparatus. I make the assertion unhesitatingly that the CO_2 Recorder, alone and unaided by other apparatus, is almost a useless con-

trivance in the furnace room, because *it* fails completely in the "first office" that I have mentioned, although it is admirably adapted to the second.

You cannot "build up furnace efficiency" with the CO_2 Recorder, because from the very nature of the apparatus it is not fitted for the testing-up and checking-out operations that go with this process of "building up." But set the Recorder to watch the fireman and the furnace, and it will keep an unerring eye upon them, reporting the first wandering footsteps from the path of efficiency.

I have examined the literature of every company making and selling CO_2 Recorders, and I fail to find a single line of instructions relative to the use of the apparatus in working out any one of the problems suggested in this treatise. The reason for this oversight is obvious, for the Recording machine is utterly inadequate to these situations. We can hope for little from the CO_2 Recorder until some broader gage manufacturer appears who is honest enough to preach the truth about flue gas analysis instruments and sell his machines strictly upon their merits within the field for which they are adapted.

Use a simple "hand" testing instrument in connection with the CO_2 Recorder, employ each apparatus in its own particular province, and if your furnaces are not performing close to the line of highest attainable efficiency the fault will be yours, and not that of your apparatus. The cost of a proper "hand" testing set is such an

inconsiderable item (only about $30.00) that I am utterly at loss to understand why the Recorder manufacturers have not long ago recognized the situation and furnished such an instrument as an accessory to every Recorder placed by them upon the market. Instead of such common-sense action, we have been told in the literature of the Recorder people that no progress could be made in the furnace room without the automatic apparatus, while the history of that machine has proved that, in most cases, no progress has been made with it.

I would not go so far as to say that efficiency cannot be built up in some degree with the unaided CO_2 Recorder, but at the very best these correcting processes with the automatic instrument are a tedious and haphazard business.

I will not speak of the complicated mechanism of the recording instrument, the sensitiveness of the apparatus and the care that is required to keep it in order. The CO_2 Recorder has been much simplified and improved since it first appeared upon the market, and the things that could be said of it three years ago are not so applicable to some of the machines at this writing.

Cost is always a factor of importance to the purchaser, and in the matter of cost and maintenance the advantages lie entirely with the "hand" apparatus and Sampling Vessel. The cost of this combination is so low that the apparatus can be afforded by any plant, no matter how

small its coal consumption, or by any engineer who wishes to perfect himself in an understanding of combustion problems.

One great advantage of the "hand" analysis instrument must not be overlooked in passing. The engineer who uses it is compelled to study furnace conditions at the furnace itself, and this is the true place to study them. An hour spent at the furnace in the first-hand study of furnace problems is worth a week's examination of charts in the engineer's office.

Let us now proceed to discover how each of the three types of apparatus may be employed in the work of "building up furnace efficiency" and cutting down the cost of power production.

We will assume the case of a water-tube boiler with vertical baffles, the furnace being of the ordinary type and hand-fired. We will also assume that the engineer is provided with each of the three types of apparatus that we have mentioned, viz., the "hand" instrument and its companion apparatus, the Sampling Vessel, an Automatic CO_2 Indicator and an Automatic CO_2 Recorder.

The Sampling Vessel, Indicator and Recorder are each piped to an individual sampling tube inserted into the breeching or the last pass of the boiler as near as possible to the point where the gases leave the heating surfaces, and in all circumstances between the damper and the boiler.

The sampling tube may be plugged at the end and perforated with a number of small holes at regular intervals, or the

tube may be left open and the perforations omitted. Experience with both classes of sampling pipe leads me to favor the latter, provided the open end of the tube may be extended to about the center of the moving gas currents. A perfect sample of gas may be drawn through such a tube, and there are no small holes to be put out of business with soot deposits. Such deposits may, of course, be blown out with steam or compressed air; but this takes time and trouble, both of which are to be avoided if possible.

We are now ready to begin our building-up operations.

The Determination Of Air Leakage.

If we are to proceed in anything like a logical way, this is the first step with the gas analysis instrument. As already seen, the question of efficiency is largely a question of excess air. Is this excess air due to anything connected with the furnace or its operations, or is it due to leakage about the boiler or the setting? Such leakage is an easy thing to cure, and, once remedied, the cure in ordinary circumstances will be quite permanent. It costs little to plug an air leak, and a daily dividend will be declared upon the investment, whatever it may be. Until we have determined the matters of leakage and infiltration, we have no means of knowing the meaning of the CO_2 as given at the breeching. Low CO_2 at this locality may

point to economy rather than waste, which would be the reverse of our expectations.

How shall we determine the extent of the air leakage? By comparing the CO_2 at the breeching with that shown at the furnace. It will be higher at the furnace, or your plant is the exception. The difference between the two points represents the dilution of the gases by air leakage and infiltration.

The disposition of the average engineer is to treat this matter of air leakage as inconsequential. It is of the greatest importance. I have tested out scores of plants, and estimate the loss due to this cause in the average case at not less than from 3 to 5 per cent. of the fuel.

In order to make a comparison between conditions at the furnace and breeching with respect to air dilution, it is obvious that gas samples for analysis must be drawn from both points simultaneously. CO_2 at either point is a fluctuating quantity, as furnace conditions are constantly changing. The comparison must be made from samples drawn under exactly the same conditions.

The hand instrument and automatic sample vessel squarely meet the situation. The sampling vessel, which is connected at the breeching, is run for about thirty minutes. At the end of this period the sample in the vessel represents the exact average of the gases at this point for the time covered.

A sampling tube is inserted into the first pass of the boiler, directly above the

furnace at the time the sampling vessel is started, the hand analysis instrument is connected, and the operator busies himself with analysis during this half-hour period, keeping a record of all of the analyses made. There should be eight or ten of them.

The sampling tube used for this purpose should be plugged at the end and perforated with small holes at intervals of about six inches. It should be long enough to extend entirely across to the opposite wall of the setting. The reason for this is that in the first pass the CO_2 will, in most cases, be found to be much higher near the center than at the sides. The higher temperature at the center tends to draw the gases in that direction, while the leakage and infiltration of air through the walls tend to dilute the gases near the sides. The difference between center and sides will be less marked in the second pass than in the first, and will almost if not entirely disappear at the breeching unless there happens to be a very pronounced leakage near that locality. A pretty thorough mixing occurs as the gases pass among the tubes, and there is a tendency toward equalization of temperature.

At the end of the half hour the sampling vessel is stopped, and a sample of gas drawn from it and analyzed. The result is compared with the average of the analyses made in the other quarter. The difference can be charged to air leakage and infiltration, and can be adduced to no other reason.

In order to determine something about the extent of air leakage into the first pass, a piece of ordinary gas pipe, open at the end, may be inserted to about the center of the pass, a sample drawn and analyzed. The pipe may then be withdrawn until the open end is about six inches from the wall of the setting and another analysis made. Comparison of results will tell you something about the leakage at the side wall.

Locating The Air Leaks.

The nearer the air leak is to the furnace, the more damage it is capable of effecting, the longer the air so admitted will be exposed to the gases and to the heating surface of the boiler.

We may now proceed to locate the air leaks. This is accomplished by sampling from each of the other passes in turn and making comparisons of the average in each case with that of an analysis made from a fresh sample drawn into the sampling vessel. In this manner we can not only locate the air leaks, but measure also the damage that the leakage into each individual pass is effecting.

Measuring Air Infiltration.

By air "infiltration" I mean the seepage of air into the gas passages through the pores of the brick. You are not justified in assuming that such infiltration is

a negligible quantity until you have measured it. It is often a serious matter. Throw a dry brick into a pail of water and watch the air bubbles. Weigh the brick before it goes in and after it comes out of the water. Remember that there is a partial vacuum on the inside of your setting and atmospheric pressure on the outside of it, and that each infinitesimal pore in every brick is busy trying to satisfy this vacuum. Measure the air infiltration in your case, and you will be surprised at the extent of it.

How will you measure it? First stop the air leaks—all of them. Examine the entire setting. Look to the blow holes and clean out doors. If your boilers are set in battery and the one next to the boiler under examination is "dead," examine the dividing walls. You may be drawing air through cracks on the side of the dead boiler into the flues or passages of the live one. Such dividing walls are usually very badly built.

When you are through with your plugging and calking operations, make another comparison between the CO_2 in the first pass and at the breeching. The difference will be chargeable to air infiltration.

Stopping Air Infiltration.

Anything to seal the pores of the brick will stop the air seepage. Glue is inexpensive. "Size" the brickwork of the settings. When the sizing is dry, apply sev-

eral coats of asphalt or fireproof paint. You have now stopped another industrious agent of fuel waste at a small expenditure of money.

I have always been an advocate of an insulation for boiler settings. Any device to keep the heat in and the air out is a good one and will justify the expense incidental to it. You apply weather strips, storm sash and storm doors to your houses. Use the same degree of common sense with your boilers. Don't employ a sieve for a setting.

One to two inches of asbestos plaster covered with canvas and the canvas covered with paint makes a serviceable "overcoat" for a boiler setting.

After stopping the air infiltration another comparison should be made between the gases at the breeching and at the furnace. If the work has been properly done the results will fully justify your best expectations.

How Much Unnecessary Air Is The Furnace Heating And Sending Up The Chimney?

Are you operating your furnace with 30 to 40 per cent, excess air—the conditions of good practice—or are you sending ten times more than the actual requirements through the furnace and across the heating surfaces of the boiler? It is unnecessary to say that indulgence in this

kind of excess is sinfully wasteful. How sinful are you, Brother Engineer?

To find the percentage of excess air above the theoretical requirement, subtract the observed percentage of CO_2 from 20.7, divide the remainder by the CO_2 percentage, and multiply by 100. For example, the percentage of CO_2 is 5. How much more air than you need for combustion purposes are you loading with heat units and sending up the chimney?

```
 20.7
  5.0
 ------
5)15.7(3.14 = excess times theoretical re-
  15                           quirement.
 ------
   7
   5          3.14
  ----          100
  20          ------
  20          314. per cent. excess.
```

N. B.—314 per cent. excess + 100 per cent. theoretical requirement = 414 per cent. total air supplied. If a 140 per cent. air supply or 40 per cent. excess means good practice, then with 5 per cent. CO_2 you are sending enough air through one furnace to keep going full-tilt with a battery of three of them.

In like manner we can at once determine the percentage of excess air referable to any given per cent, of CO_2. The following table will be interesting in this connection, and will require little explanation:

Per Cent CO_2	Per Cent Air Excess.	Increment Air Excess.
15	38.	..
14	47.8	9.8
13	59.2	11.4
12	72.5	13.3
11	88.1	15.6
10	107.	18.9
9	130.	23
8	158.7	28.7
7	195.7	37
6	245.	49.3
5	314.	69
4	417.	103.5
3	590.	172.5
2	935.	345
1	1970.	1035

At 15 per cent. CO_2 the percentage of excess air is 38, and at 14 per cent. CO_2 the percentage is 47.8. It will be noted that, in dropping from 15 to 14, there is an increment in the air excess of 9.8 per cent., and that in dropping from 2 to 1 per cent. CO_2 there is an increment in the excess of 1035 per cent. The conditions grow from bad to worse in a geometrical ratio of progression as we descend the scale of CO_2.

Take the gas analysis instrument and ascertain where you show up, Mr. Engineer. Assuming that you are a stranger to flue gas analysis and that your conditions are no better and no worse than the average, your percentage of CO_2 will be somewhere between 5 and 7. At 7 per cent. you are heating enough unnecessary excess air to keep a duplicate of your furnace plant going. At 5 per cent. CO_2

the excess would almost keep 2 additional plants running; at 3 per cent., 4 plants; at 2 per cent., 6; and at 1 per cent., 14. I have seen furnaces operated with less than 1 per cent. CO_2. Think of it! Enough air passed through one boiler furnace to keep fifteen of them going!

The writer recently had occasion to visit a plant where conditions as to excess air were about as bad as they make them. The gas analysis instrument showed about 2 per cent. CO_2, and enough observations were taken to prove that this was a fair average under which the furnace was operating. It was a case of chain-grate stoker, a large boiler unit and very light summer load. The remedy called for was less grate surface, but changing grate surface with this type of stoker is no easy matter. "What is the use," said the engineer, "of trying to do anything under such circumstances?" I asked him if he did not think the CO_2 might be increased from 2 per cent. to 3 on the average if careful attention were given to draft regulation and one or two other matters. "Oh, yes," he replied, "I suppose so; but what does 1 per cent. CO_2 amount to?" One little per cent. of CO_2. It depends entirely upon where that 1 per cent. is located. Raise the CO_2 percentage from 2 to 3, and you have accomplished almost as much saving as in raising it from 4 to 15. A little CO_2 means a lot when you are operating in the bad lands of engineering.

Does Low CO_2 At Breeching Express Waste Or Economy?

As the stopping of air leaks and infiltration will take some time, it is not necessary to defer our other testing-out or building-up operations until the work is completed. We may proceed at once as soon as we have determined the meaning of the CO_2 at the breeching.

I have already shown that the damage due to the air leak is proportional to its nearness to the furnace. Now let us assume the case of a reasonably tight setting and a large air leak into the breeching between the sampling tube and the boiler. Such leaks are not uncommon, as the metal of the breeching often tends to warp or spring away from the boiler. Air will enter here and dilute the gases, and the percentage of CO_2 will be reduced to the extent of such dilution. What is the effect of such dilution? The gases have left the heating surfaces of the boiler, which is no further concerned with them. The only tendency in this case is to check the draft and relieve the air pressure at the furnace. There are circumstances, as every engineer knows, under which this would be an aid rather than a detriment to economy.

Let me cite a case directly to the point and taken from the note-book of my experiences:

Analysis showed less than 3 per cent. CO_2 at the breeching, while the first pass gave 9 per cent., the second a little less

and the third between 7 and 8. This pointed conclusively to leakage into the breeching or into the last pass near the breeching. The leak was located at the breeching connection and stopped. Co_2 rose at once in the breeching to nearly 6 per cent. Did this result express any economy in fuel consumption? It required another series of analyses at the various passes to answer this question. The CO_2 at the furnace and throughout the gas passages of the boiler had fallen almost in proportion to the rise in the breeching. The cause was obvious. We had increased draft pressure at the furnace, and the air which had formerly been inspirated at the breeching was now being drawn in at the furnace, and, sweeping every foot of the heating surfaces of the boiler, was doing the maximum of damage. We were wasting more fuel than with the leak in full operation. The draft was reduced, the fires slightly thickened and CO_2 rose in the first pass to 12 per cent., with a corresponding increase all along the line.

ANALYSIS AT THE FURNACE EXPRESSES FURNACE EFFICIENCY. ANALYSIS AT THE BREECHING EXPRESSES FURNACE EFFICIENCY MINUS THE EFFECT OF AIR DILUTION POSTERIOR TO THE FURNACE. I trust it is now apparent why we are unable to proceed with any intelligence until we know the meaning of the analyses made at the breeching.

It must be recognized that, so far as we have proceeded with our testing-out operations, the hand instrument and gas sampling vessel are well-nigh indispensable. Two automatic CO_2 Indicators or Recorders would be required to effect the same results in the same period. The high temperatures near the furnace, however, would tend to oxidization of the metal sampling tube. This tube may be withdrawn and allowed to cool between analyses with the hand instrument, but cannot be withdrawn for such purpose when connected with an automatic machine in operation.

What Draft Is Consistent With The Most Economical Operation Of Your Plant?

This is in some particulars the most important of all furnace questions. How many engineers are able to answer it? How many are even able to say exactly what draft they have? That the draft is "good" or that it is "poor" conveys very little information. How many operating engineers are provided with a suitable draft gage? How many who have such a gage ever use it? When it comes to the uses and abuses of draft, how many have any strictly definite ideas upon the subject?

The sole end and aim of the draft is to *consume* fuel. We are concerned in *sav-*

ing it, and we must have effective means for curbing and controlling the pull of the chimney. We must regulate the draft intelligently. A difference of a twentieth of an inch in your draft will work a surprising difference in your fuel consumption. This statement you can verify for yourself. It emphasizes the great importance of draft regulation. Each furnace should have a separate damper, easily and quickly adjustable, and the draft requirements of each individual furnace should be studied separately. Don't undertake to regulate the whole battery by one damper in the main breeching.

As a general proposition, the least draft that you can employ and carry your load is the best for the coal pile. This will not apply, however, in all cases, as the draft may be reduced to the point where an excess of combustible CO may be formed with a resulting waste of over 10,000 heat units for every pound of Carbon represented in the CO carried up the chimney. In such case the obvious remedy would lie in the reduction of grate surface and the employment, perhaps, of a little more draft. That draft is the best in your case which gives the highest percentage of CO_2 and a chimney that contains no combustible.

How shall we proceed to quickly and authoritatively determine what this draft is by the use of the gas analysis instrument? Bring the hand analysis instrument and draft gage into requisition. Carefully note the condition of the fires,

the position of the ash-pit doors, hoods or dampers admitting air to the grate, read the draft gage, and as quickly as possible draw a sample of gas and analyze it. Next change the draft a tenth or a twentieth of an inch and repeat the experiment, being careful to see that all the other conditions are the same as on the first analysis. If you have increased the CO_2, you are moving in the right direction.

The importance of carefully noting the condition of the fires when testing out the draft cannot be overestimated. If it is a hand-fired furnace, conditions in the furnace chamber are constantly changing. First you have the open fire door with an inrush of a large quantity of undesired air. You add fresh fuel, which thickens up the fire, reducing the quantity of excess air that may find its way into the fire-box by way of the grate. If you are burning bituminous coal, you next get a great volume of combustible gas in the furnace, which requires Oxygen. The demand for air is at the maximum. The fire now begins to burn down, the demand for air diminishing, while the supply increases as the fuel bed becomes thinner. It is a perverse situation. It will be best to make all your CO_2 tests to determine the draft problem either immediately before or immediately after firing, and the handy hand instrument lends itself to this as no automatic recorder can possibly do.

The "lag" in the pipes leading to the automatic CO_2 instrument has, in the past,

been one of the things precluding its use in obtaining a prompt and ready answer to the draft question. In the earlier machines the lag amounted in some cases to as much as 20 minutes, depending upon the distance of the Recorder from the boiler. So much improvement in this particular has been made in the later machines that the criticism is robbed of much, if not all, of its force.

Should The Draft Be Regulated By The Damper Or The Ash Pit Doors?

As a general proposition, one must favor the damper. The ash pit doors serve to fix the quantity of air that may have access to the grates, but they cannot reduce the quantity of air inspirated into the furnace and gas passages at other places. There will be some leakage about the furnace doors, and unless the setting has been made absolutely air-tight there will be the leakage and infiltration already referred to. Checking the draft at the ash pit increases the draft pressure at every other point where air may enter.

The air admitted below the fire has a certain relation to the air that should be admitted above it. It may accordingly be necessary, especially if bituminous coal is employed, to look to the air supplied at the grate, and the "over air" supply also, as well as the damper.

Always look to the gas analysis instrument for the answers to these questions.

Don't assume or guess at anything. *Do* not be biased by any previously formed notions that you may entertain. You may be right or you may be wrong. If you employ the gas analysis instrument at all, rely absolutely upon its findings.

How Does Excess Air Affect Stack Temperatures?

As well ask if a tin can tied to a dog's tail will keep it from loitering by the wayside. The little heat unit needs no can or rubber heels to make it rush for the chimney. Excess air always means a rise in stack temperatures. Increase the draft, and you decrease the time that the hot gases are permitted to associate with the boiler. You not only raise stack temperatures, but, by increasing the speed of the gas currents, you greatly add to the volume of gas passing up the chimney in a given period, and thus the waste of heat energy is multiplied.

Admit excess air at the breeching, and you cool the stack gases, decreasing the draft in the stack and further decreasing the pressure at the furnace by partly satisfying the chimney with a supply of air from the other quarter. Open the damper in the breeching, and you increase the pressure at the furnace. This adds both to the speed and volume of the gases and raises the temperature in the breeching.

Are The Fires Too Thick Or Too Thin?

If, after running the gamut of draft regulation, you are unable to raise the CO_2 to a satisfactory percentage, look next to your fires. A thin fire will pass an excess of air into the furnace through the grates and the fuel. A partial closing of the ash pit doors will tend toward a remedy, but you have already experimented in this direction. Thicken your fires and test the gases. Build them up gradually, and keep on building as long as you note improvement. You are experimenting now to determine one thing—the effect of thickening the fuel bed. Forget for the time being all questions as to clinkers—forget everything but the subject in hand. Thickening the fire will undoubtedly aggravate your clinker troubles, and you may lose here all that you gain by the thickening. The subject of slag will be treated as a separate problem. There may be some way to avoid or minimize it. Your present inquiries are in the direction of dissection and analysis, and each line of investigation should be carried to an extreme conclusion. When you have secured all the data obtainable, you may then proceed intelligently in the light of the information secured to bring everything bearing upon furnace management and operation into working harmony with every other.

Are The Heating Surfaces Of The Boiler Dirty?

Now, how on earth can the gas analysis instrument be employed to tell you anything about scale or soot upon the heating surfaces of the boiler? Suppose, for example, the daily averages of CO_2 are substantially constant, but a marked increase is noted in the temperature of the escaping gases. You know that the increased temperature is not due to increased draft, for such draft increase would, in all probability, have lowered the CO_2 averages; moreover, there is the testimony of your draft gage. The increased temperature under these circumstances indicates a lack of heat absorption, and points to the use of the soot blower and the tube cleaner.

Should The Coal Be Fired Dry Or Wet For Greatest Economy?

This is more or less of a mooted question among engineers. It depends upon circumstances, the principal circumstance being the condition and character of the fuel, the wets usually having the best of the argument. Refer this question, as you should every other, to your gas analysis instrument. If the hose gives you more CO_2, use it.

What happens when we wet the fuel? There are two sides to the ledger in this case, as in almost every other.

It takes heat units to evaporate the water applied to the coal, and the business of these heat units is to evaporate the water in the boiler. This is the debit side of the ledger.

When a shovelful of wet coal goes into the furnace, the first thing that happens is the evaporation of the water into steam. This is followed by the decomposition of the steam into the elements Oxygen and Hydrogen. The Hydrogen is next ignited and burns back again into water, returning to the furnace all of the heat abstracted from it in the operation of decomposition. Some of this heat will, of course, be lost by radiation, more of it will be discarded to the chimney, and some of the hydrogen may escape without being consumed. The decomposition of water in this manner for fuel purposes accordingly possesses no attractions from the view point of economy. But let us draw no hasty conclusions, for several other things are also happening.

Combustible gases are being evolved from the fuel. They must not reach the chimney. They must be ignited. The Hydrogen flame assists in ignition.

When water and incandescent coke come into contact with each other there is an evolution of CO as well as Hydrogen—the Oxygen of the water uniting with the Carbon of the coal to form Carbon Monoxide. This gas rises into the furnace chamber and burns with the Hydrogen. The area of combustion is accordingly extended, and instead of an in-

candescent bed of fuel we have a flaming furnace, through which no combustible gas can pass if it is supplied with Oxygen.

Fine coal, when thrown into the furnace, tends to pack, particularly if there is much ash and foreign matter in it. If it is wet, the expanding water when it rushes into steam loosens it and renders it porous. Air can more readily find its way through the fuel and more easily search out those particles of the combustible that are associated with ash and other slag-forming materials. Among the results you may count upon less combustible in the ash pit and less slag and clinkers to worry your fireman.

Wetting fine coal also causes it to burn more uniformly. There will be fewer cracks and bare spots in the fuel—less opportunity for a diluting excess of air to enter.

Don't turn down a thick fire until you have tried wetting the fuel.

I have now given you the credit side of the ledger.

Does It Pay To Employ Steam Jets?

Great Cæsar! NO. The steam jet is a relic of the dark ages of engineering. Gas analysis and common sense unite in damning it. If you need water in the fire-box, get it from headquarters—turn the hose on the coal pile. Don't heat the water twice, and don't rob the boiler. There are rational ways of preventing

smoke without resorting to any such archaic and wasteful expedient.

If you think it takes no steam to run a jet, condense the water from one of them and weigh it. Test the gases for CO_2 and see how much excess air you are siphoning into the furnace. Test them for CO and see how much of this gas the blast of the jet is driving out of the combustion zone and discarding to the chimney. Look out for scale on the fire side of your tubes, and look out for pitting.

Why Are You Smoking?

Gas analysis will solve this question for many a perplexed engineer. Knowing "why," he should be able to apply the remedy.

What are the requisites of smokeless combustion?

Sufficient Oxygen *over* the fire to mix with the combustible furnace gases.

Means for promoting such mixture.

An igniting temperature throughout the combustion area.

Sufficient time and space for the gases to complete the act of combustion before encountering the cold surfaces of the boiler.

If any one of these requisites is lacking, your chimney will smoke like Sodom.

Draw a sample of gas when the smoke is at its height and test for CO_2, Oxygen and CO. If the Oxygen percentage is less than about six times that of the CO,

it may be presumed that you require more air in the furnace. Apply it over the fire.

If the Oxygen pencentage exceeds the ratio to the CO above given, the chances favor incomplete mixture; but we must look first to the question of temperature and that of time and space. Mere inspection should give us a line upon these questions. We can tell by observation if the live flames are impinging upon the heating surfaces of the boiler.

If the problem narrows itself down to that of mixture, little can be done short of altering furnace construction. I cannot further enlarge upon these matters here, as they are fully discussed in my work, "Combustion and Smokeless Furnaces."

What Method Of Firing Gives The Greatest Economy?

Each of the well-known methods of firing has its advocates. Try each of them for a short period and fall back upon the hand analysis instrument and sampling vessel, searching the gases for Oxygen and CO, as well as Carbon Dioxid.

I personally favor light and frequent firing, but this involves an open furnace door, a larger percentage of the time than is required by other methods. An automatic damper regulator, operating to check the damper when the fire door is opened and to open it when the fire door is closed, is worth considering as a furnace appurtenance in this connection.

How Much Combustible Is Passing Up Your Chimney?

This question can only be answered by a determination of the CO in the stack gases. The machine that is limited to CO_2 is, of course, out of the question in attacking this problem.

"Smoke means waste." What is the extent of the waste of it? Combustible, as I have already pointed out, often occurs also in the gases when what we call smoke is absent.

Can you eliminate this combustible from the gases without sustaining a loss that exceeds the saving? Can you eliminate the CO without increasing the excess air and decreasing the CO_2? If you save $2.00 by burning up the combustible gases and lose $4.00 by heating the excess air employed in the process, how much of a gainer are you? To burn soft coal smokelessly is a simple matter; but to burn it smokelessly and, at the *same time*, economically, "is up another street" altogether. If the men who are selling "smokeless furnaces" were compelled to put their devices up against the gas analysis instrument, nine-tenths of them would go out of business.

Bituminous coal can be burned both smokelessly and economically, but one of the nicest problems is involved in the whole range of combustion engineering. The gas analysis instrument will tell you at once if the furnace is measuring up to the requirements.

Are You Using The Grate Best Adapted To Your Conditions?

Use a grate with air spaces in it. If you are unable to burn your fuel properly without CO, with a high percentage of CO_2 and with a reasonable draft at the furnace—two to three-tenths of an inch, the load being normal—look to the air spaces in the grates. The purpose of a grate is to burn fuel, not save it; and that grate is the best for your purposes which offers the least resistance to the passage of air and at the same time supports the fuel.

Is There Too Much Or Too Little Grate Surface?

If the CO_2 at the furnace is low and excess air is not entering by the doors or otherwise gaining access except through the grates, then the fuel bed is too thin to satisfy the demands of good practice. If you cannot thicken the fuel bed without blowing off the boiler, you have too much grate surface. If all of the conditions necessary to complete combustion are present and you are unable to keep clear of combustible in the stack gases, you have too little grate surface.

Is The Fireman Obeying Instructions During Your Absence As To The Methods Of Operation?

We will assume that you have now determined upon the methods of furnace

management that yield the highest degree of efficiency consistent with your load and the other conditions under which you are forced to operate. A few hours spent in careful examination of the furnace in operation, a little reasoning applied to the data obtained, and you have formed quite an accurate judgment as to the proper management of everything connected with the furnace. Formulate a set of rules and instruct your fireman. Try these rules for a day and note the average percentage of CO_2 at the end of the run. Vary these rules slightly, and try it for another day. The CO_2 percentage will tell you whether the variation is in the right or the wrong direction. Within a week you will be getting out of the furnace all of the efficiency of which it is capable. You will know what average CO_2 may be maintained under these rules of operation. It is now up to the fireman to maintain this CO_2 standard or explain his failure. If he is remiss in his duties the percentage of CO_2 will tell you.

How Can You Engender A Spirit Of Rivalry Among Your Operatives?

Get the men to vieing with one another in the strife for efficiency, and results will begin to happen in your furnace-room. One of the greatest contributing factors of efficient furnace operation is an interested operative. The value of the interested man is increased when he is given

the spur of beating the other fellow. If you have a proper gas analysis apparatus and understand human nature, the rest is easy.

The experiment of paying a bonus for efficiency has been tried in some of the larger power plants, with the most satisfying results. Your fireman will work his shirt off for a bonus of five dollars, and it is a pretty mean kind of employer who will not give up five when the fireman is saving a hundred.

Explain to your firemen that the more CO_2 there is, the smaller will be the coal consumption, and that the smaller the coal consumption the more efficient the operative. Teach them how to make CO_2, keep a separate record for each watch and for each man in the watch, keep the men informed daily as to the state of the records, and the rest will be easy.

Have They "Changed Coal On You"?

The coal may be "changed on you" and a mere inspection of the substitute be insufficient to detect it. Two coal piles may look alike, but be widely different in quality. The higher the Carbon content of the coal, the more CO_2 you may expect from it, for the gas is derived from Carbon. The more foreign matter there is in the fuel, the more air will be required to burn it.

If you know that the fireman has observed all of your rules to the letter and

the CO_2 average falls below what you know it should be, the circumstance may be ascribed with reasonable certainty to a change in the condition of the fuel.

The series of problems might be extended even further. Flue gas analysis will apply in some measure to every question bearing upon furnace efficiency. THAT FURNACE IS THE MOST EFFICIENT WHICH COMPLETELY CONSUMES THE COMBUSTIBLE WITH THE LEAST SURPLUS OF AIR. This is the yard-stick by which we must measure the furnace under all circumstances. I produced it at the beginning of this discussion, and I now leave it with you.

Of course, I know that your load varies, that half of your boilers are banked during the middle of the day, and that you work the life out of all of them night and morning.

I know the lights may suddenly be required throughout the building, and that your peak load may come on in an instant and without warning.

I know that you must carry your load irrespective of CO_2 or any other commodity that may be in your stack gases. I know all about the vicissitudes of operating a steam-power plant and the troubles of the engineer.

I know of the crimes that have been committed against good engineering in the selection and design of boiler-room equipment, and I know how far the average plant must necessarily fall short of ideal

conditions under the most intelligent management.

But knowing all of these things I am compelled to observe that the engineer can urge no legitimate excuse for his failure to make the best possible use of the means at hand, however bad and insufficient those means may be.

I have no means of knowing what average CO_2 you may be able to show and carry your load. If everything is in your favor it may be as much as 12 or 14 per cent. If things are not in your favor it will be whatever your intelligence as an engineer and your grasp of the problems I have outlined will admit.

As to the form of gas analysis apparatus you should employ, that is a matter upon which you will exercise your own judgment and discretion. The author has tried impartially to present the various types and to comment fairly upon the claims and advantages of each. He asserts a peculiar right to point out the limitations of the CO_2 Recorder, for he has himself designed and applied for patent upon several types of this interesting apparatus. If what has been said in these pages in any way affects the manufacturers of automatic instruments, then the writer must take his own medicine and suffer along with the rest.

I have no quarrel with the CO_2 Recorder, if a "hand" testing apparatus is provided and furnished as an accessory to it. Sufficient reasons have been set out

for my views on this matter, and it is unnecessary to recapitulate them.

Whatever form of apparatus you may elect to employ, make gas analysis A PART OF THE DAILY ROUTINE of the boiler room. Do this, and the results will astonish you; fail to do it, and you might as well let gas analysis alone.

When you have provided yourself with a gas analysis instrument, begin at the beginning and reach the top by working up from the bottom. DON'T TRY TO GO UP FROM THE TOP DOWN.

CO_2 is the important thing. Don't worry about O and CO until you have worked the CO_2 inquiries for all there is in them. If your load is not abnormal and your furnace possesses no freak characteristics, you should operate with an average of 12 to 14 per cent. CO_2. When you have attained such average, there will be little to fuss about in connection with the other gases. They will take care of themselves.

"Building up furnace efficiency" is a simple matter once we understand what an efficient furnace really is and are provided with simple and practical apparatus for testing the flue gases.

"Oh, yes," you say, "but this sort of thing means trouble, and I am a busy man." If your house is afire and the garden needs sprinkling, which way will you run with the pail of water? Do the most important thing first and let the things slide that are inconsequential.

A mastery of your gas analysis appara-

tus, whichever it is, and a reasonable amount of engineering gumption are all that you will require in the practical work of flue gas analysis and its successful application to your furnace problems.

Speaking of the trouble again, let me paraphrase David Harum:

"A reasonable amount of" trouble "is a good thing for" an engineer; "it keeps him from broodin' on bein'" an engineer.